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Biomedical Engineering – Past, Present, Future

Medicine and health care have changed dramatically in the past few decades and they depend on high technology for prevention, diagnosis and treatment of diseases, and for patient rehabilitation. Modern biomedical research and health care are provided by multidisciplinary teams in which biomedical engineers contribute to the advancement of knowledge equally as medical professions. Biomedical engineering represents one (out of two) the most rapidly growing branches of industry in the developed world [1] (the other are sustainable and renewable energy sources). The new knowledge gained by basic biomedical engineering research (at gene, molecular, cellular, organ and system level) has high impact on the growth of new medical products and boosts industries, including small and medium size enterprises (SMEs). SMEs are expected to bring to the market new products and services for health care delivery [2]. Health is the major theme of the specific Programme on Cooperation under the European Seventh Framework Programme, with a total budget of €6.1 billion over the duration of FP7. The objective of health research under FP7 is to improve the health of European citizens and stir up the competitiveness of health-related industries and businesses, while addressing global health issues, life improving and develop life saving technologies. Hospitals and other medical institutions have a commitment to take care of all kinds of high technology devices including the hospital information systems, networks and their safety and security. Growing technological participation in health services enforces the support of technologically specialized personnel, trained clinical engineers. Worldwide, the educational system has adopted the curricula of biomedical engineering and of clinical engineering. Professional organizations are building certification system for biomedical and clinical engineers and the continuous education (life long learning) structures. The development of biomedical engineering and its affirmation has mainly appeared in the last 50 years, first as a result of development in electronic industry while later it started developing at its own pace. In the first part of this paper, we address the development of biomedical engineering in that period and present our views on the development of biomedical engineering in the future. The second part is devoted to the International Federation for Medical and Biological Engineering (IFMBE), the largest organization of biomedical engineers in the world which celebrated its 50th anniversary in 2009. In the third part, we recall our memories to the founder of biomedical engineering in Croatia, prof. Ante Šantić and his achievements in biomedical engineering, and present the state of art of biomedical engineering research and education in Croatia.

Key words: biomedical engineering, biomedical electronics, health care, clinical engineering, medical physics, International Federation for Medical and Biological Engineering (IFMBE), BME education

Biomedicinsko inženjerstvo – prošlost, sadašnjost, budućnost. Medicina i zdravstvena zaštita su se dramatično promijenile u posljednjih nekoliko desetljeća, i ovisе o visokoj tehnologiji za prevenciju, dijagnostiku i liječenje bolesti, i za rehabilitaciju pacijenata. Moderna biomedicinska istraživanja i zdravstvena zaštita osigurava se multidisciplinarnim timovima u kojima biomedicinski inženjeri doprinose unapređenju znanja jednako kao i medicinski stručnjaci. Biomedicinsko inženjerstvo predstavlja jedno (od dvije) najbrže rastuće grane industrije u razvijenom svijetu [1] (druga grana su održivi i obnovljivi izvori energije). Nova znanja stečena temeljnim istraživanjima u biomedicinskom inženjerstvu (na razini gena, molekula, stanice, organa i na razini sustava) imaju velik utjecaj na razvoj novih medicinskih proizvoda i jačanje industrije, uključujući i mala i srednja poduzeća (MSP). Očekuje se da mala i srednja poduzeća na tržište donesu nove proizvode i usluge za zdravstvenu skrb [2]. Zdravlje je glavna tema specifičnog programa o suradnji u okviru europskog sedmog okvirnog programa (FP7), s ukupnim proračunom od 6,1 milijarde eura tijekom trajanja FP7. Cilj istraživanja u području zdravstva u okviru FP7 je poboljšati zdravlje europskih građana i povećati konkurenciju u okviru zdravstvene djelatnosti i industrije, a istovremeno voditi računa o globalnim zdravstvenim problemima, poboljšanju života i razvoju tehnologija za spašavanje života. Bolnice i druge medicinske ustanove imaju obvezu voditi brigu o svim vrstama uređaja visoke tehnologije, uključujući bolničke informatičke sustave, mreže i te o njihovoj sigurnosti. Povećanje udjela tehnologije u zdravstvu proizvelo je potrebu za tehnološki specijaliziranim osobljem, kliničkim inženjerima. Diljem svijeta, obrazovni sustav je usvojio visokoškolske programe biomedicinskog inženjerstva i kliničkog inženjerstva.

Profesionalne organizacije su izgradile sustav potvrđivanja za biomedicinske i kliničke inženjere i za njihovo kontinuirano obrazovanje (cjeloživotno učenje). Razvoj biomedicinskog inženjerstva i njegova afirmacija je započela u posljednjih 50 godina, kao rezultat razvoja elektroničke industrije, a kasnije se biomedicinsko inženjerstvo nastavilo razvijati vlastitim tempom. U prvom dijelu ovog rada, govorimo o razvoju biomedicinskog inženjerstva u početnom razdoblju i predstavljamo naše poglede na razvoj biomedicinskog inženjerstva u budućnosti. Drugi dio posvećen je Međunarodnoj federaciji za medicinsko i biološko inženjerstvo (IFMBE), najvećoj organizaciji biomedicinskih inženjera u svijetu koji je proslavila svoju 50. godišnjicu u 2009. godini. U trećem dijelu, podsjećamo se na utemeljitelja biomedicinskog inženjerstva u Hrvatskoj, prof. Antu Šantića i njegova dostignuća u području biomedicinskog inženjerstva. Konačno, predstavljamo sadašnje stanje istraživanja i obrazovanja u području biomedicinskog inženjerstva u Hrvatskoj.

Ključne riječi: biomedicinsko inženjerstvo, biomedicinska elektronika, zdravstvena skrb, kliničko inženjerstvo, medicinska fizika, International Federation for Medical and Biological Engineering (IFMBE), obrazovanje u području biomedicinskog inženjerstva

1 INTRODUCTION

Biomedical Engineering (BME) is a field of engineering originating from an interdisciplinary background of different engineering sciences and principles and study of biology, medicine, behavior and health. BME aims to improve human health and quality of life. Research in biomedical engineering creates knowledge from molecular and cellular level to the level of organs and the body as a system, resulting in new devices, materials, processes and software. New technologies are implemented in prevention, prediction, diagnostics and treatment of disease, patient care and rehabilitation. In the same way as medicine, BME has developed numerous specializations. Those based on electrical phenomena from the body and electrical or electronic devices and systems which measure signals and process signals and information have their roots in biomedical electronics: medical instrumentation, monitoring systems, physiological signal and medical image acquisition and processing, minimally invasive surgery, image guided surgery, robotics in therapy and rehabilitation, artificial organs and prosthetics, etc. Another large group of specializations is present in biomechanics and biomaterials, both enabling technologies for extremely sophisticated passive and active implants. Research in the field of cellular engineering, tissue engineering and stem cell engineering will enable designing of artificial organs of biological origin very soon. Gene technology supported by bioinformatics offers enormous benefits for health care and disease prevention by modifying genes and transferring them to new hosts. Medical informatics today also includes connecting of the information sources through information and communication technologies making information available to medical staff also from a long distance, no matter whether the information is acquired from the patient body or from an electronic archive. Clinical engineers are professionals

who support and advance patient care by applying engineering and management skills to healthcare technology and they typically find their jobs within clinical settings with primary aim in patient safety and quality insurance. Traditionally, biomedical engineers collaborate with medical physicists who as a profession take care of radiotherapy planning and protection of ionizing radiation.

2 FROM THE EARLY DAYS TO THE PRESENT

The beginning of modern biomedical engineering as a new and emerging technology started shortly after the invention of the silicon transistor in the early fifties of the 20th century. Miniaturisation of diagnostic and therapeutic devices, their lower power consumption, portability and integration of firstly automatic functions and later building into the devices some kind of intelligence enabled their applications in practically all branches of medicine. It is impossible to enumerate all successful biomedical devices and methods in a short article but a visit the Hall of Fame of the American Institute for Medical and Biological Engineering (AIMBE) [3], enables one to recall a lot of devices used in modern healthcare: from X-ray imaging devices, cardiac pacemakers [4], antibiotic production technology, artificial kidney from the early days, computerised tomography and magnetic resonance imaging devices and methods, up to genomic sequencing & micro-arrays, positron emission tomography and image-guided surgery from the last decades. Contribution of technology to medicine can be noticed also through the choice of the laureates of the Nobel Prize. The Nobel Prize in Physiology or Medicine in 2003 was awarded to Paul C. Lauterbur and Sir Peter Mansfield for their discoveries concerning magnetic resonance imaging [5] and in 2009, Nobel Prize for physics

was awarded to Willard S. Boyle and George E. Smith, for the invention of the charge-coupled device (CCD), which is used in most digital camera sensors and has a spread medical application for imaging the inside of the human body, in diagnostics and for microsurgery [6].

The technology develops also due to the current, altered needs of the health care [7]. Population projections in Europe show dramatic growth of elderly population: those aged 65 years or over (17.2 % in 2009) will account for more than 30.0 % of the EU's population by 2060 [8]. The impact of aging will cause increased social expenditure related to healthcare, while the population will expect reasonably priced high quality care. Only technological advances can enable the industry to meet these conditions. Today, healthcare industry intensifies efforts for solutions of the long-term treatments for chronic diseases in the aging patient population. One of the challenges is how to achieve healthcare services and healthcare quality.

3 A GLIMPSE INTO THE FUTURE OF BME

For research in biomedical engineering, there is no limit because humans are demanding and would like to extend the quality of life and the life itself for many years. In the next decades, one can expect that research will concentrate and bring to the market devices for restoring the functions of tissue, by more sophisticated implantable electronic devices, e.g. implantable systems for heart resynchronisation. In future, there will be patients with more than one implantable electronic device and these devices will have to learn how to communicate and adjust their performance in order not to cause any harm due to joint action. The next step will probably be functional tissue engineering where tissue will be grown from biological material - cells, placed into the body into the right position, and then the function of the newly implanted tissue will be restored. Of course, there is still a lot to be learned on how to produce biological materials which have properties close to, or the same as human living tissue and can withstand the same forces and strain. Image guided surgery will enable precise access to the place of interest and positioning of the implant to the right position. At the same time, data transfer and information processing in medical applications will become more demanding due to increased number of sensors for measurement or monitoring of physiological and biomechanical quantities, from the surface and/or from the inside of the body. Closed loops of sensors, e.g. glucose sensors implanted into the body and external actuators e.g. the insulin pump, mimic organs like the pancreas with the intention to regulate the blood glucose level in the same way as a healthy human organ. In near future, people will learn how to design more complex integrated biological structures – the organs. Tremendous advancements have been

made in the development of artificial eye and ear, bringing sight and hearing to blind and deaf. The newest retina implant has a sensor of only 3 by 3.1 mm in size, and consists of approximately 1,500 light-sensitive microphotodiodes [9]. Also, a cochlear implant does not cure deafness, but is a prosthetic substitute for hearing with limited quality. There are two major fields of intensive research which will improve the current results, neural interfaces and neuroscience. The need for neural interfaces fosters development of new biocompatible materials for neural prosthesis, especially among the nanomaterials and nanotechnology. For example, the main problem in clinical application of a bionic eye is how to attach the outputs of the sensors to the visual nerves and nanotubes appear as a possible technological solution. In neuroscience, scientists are researching how the brain works and for processing and understanding the complexity of all the data acquired, engineering knowledge is necessary. For better understanding of the data in neuroscience, fusion of imaging modalities is necessary and for better diagnosis, medical experts still need better resolution of all image modalities.

Environment in the biomedical engineering world is constantly and rapidly changing, the knowledge is rapidly increasing and there is a constant need for increasing the resources and equipment necessary for the demanding research. International collaboration for biomedical engineers and other scientists and professionals in medicine and health care is a must and the pioneers of biomedical electronics realized it in 1959 and they founded the International Federation for Medical and Biological Engineering [10].

4 50TH ANNIVERSARY OF THE IFMBE

The International Federation for Medical and Biological Engineering (IFMBE) is primarily a federation of national and transnational organizations that represent national interests in medical and biological engineering: building up biomedical engineering and health research and professional networks, exchange of knowledge, fostering international mobility of researchers and students, making medical and engineering knowledge and health care available to all. The objectives of the IFMBE are scientific, technological, literary, and educational.

The International Federation was founded in 1959 in Paris during the 2nd International Meeting of engineers, physicians and physicists who were mainly researching in the field of Medical Electronics. At that time there were few national biomedical engineering societies. For this reason researchers and professionals in the discipline joined the Federation as Associates. After a larger number of national BME societies were founded, these societies became affiliates of the Federation. In June 2011, the Fed-

eration has an estimated number of 120,000 members in 62 affiliated national or transnational BME organizations.

The IFMBE has also achieved a close association with the International Organization of Medical Physics (IOMP) [11]. Since 1976, the two organisations have been jointly organizing international conferences every three years. The two international bodies have established the International Union for Physical and Engineering Sciences in Medicine (IUPESM) [12] and they act together on international scene in matters related to health and patients. IUPESM is recognized by the International Council of Scientific Unions (ICSU) [13], representing a global membership that includes both national scientific bodies (121 members) and international scientific unions (30 members). The membership of IUPESM in the ICSU gives visibility and legitimacy to the profession of biomedical engineers and medical physicists. The ICSU starts global projects such as the inter-union initiative on Science for Health and Well Being which in different time periods deal with specific topics, e.g. "Science and Technology in the Care of Patients and Persons with Disabilities" or "The Impact of Technology on Hypercommunicable Disease Processes".

During the last decade the IFMBE has promoted biomedical engineering at scientific conferences and meetings, and among political decision makers, representatives of the health care systems and the medical device industry. Active cooperation of IFMBE with the World Health Organization (WHO), where IFMBE acts as the only accredited non-governmental organization (NGO) from the field of biomedical engineering, enabled the Federation to present several resolutions which are important for biomedical engineering as a profession and for technology in medicine in general [14]. IFMBE is involved in a number of global initiatives that promote health like the World Alliance for Patient Safety. In the World Standards Cooperation, it represents patients in matters of medical equipment and technology safety and security.

IFMBE is primarily a learned society and its aim is to encourage BME research and application of knowledge for the benefit of science and patients. It does not fund scientific research projects, but since 1962 it is publishing the peer reviewed journal *Medical and Biological Engineering and Computing* (MBEC), and the electronic version of the Journal is available on-line. Though MBEC is a "general" biomedical engineering journal, the editors foster publishing of special thematic issues, e.g. on Microbubbles [15], Shoulder Biomechanics [16] or Neurodynamic Insight into Functional Connectivity and Cognition [17]. On yearly basis, the Journal awards the best paper published in MBEC the Nightingale Prize [18, 19]. Since 2006, the IFMBE Proceedings Series which covers publication of papers from IFMBE sponsored conferences and

some of the IFMBE endorsed conferences is also available at the web site.

5 BIOMEDICAL ENGINEERING IN CROATIA

The pioneer of biomedical engineering in Croatia is Prof. Ante Šantić. He received his D.Sc. degree in 1966 in electrical engineering from the University of Zagreb, Faculty of Electrical Engineering. In his thesis, he elaborated the application of the parametric amplifiers for recording of bioelectric potentials, in particular the potentials of the brain (EEG) [20]. He was the head of Electronics Laboratory at the Institute of Electrical Engineering in Zagreb, where he developed special electronic instrumentation and medical instrumentation. The Institute became the leading manufacturer of electroencephalographs in Central Europe. In 1970, Šantić joined the University of Zagreb, Faculty of Electrical Engineering. From 1971, he started teaching a course in Biomedical Electronics and founded the Biomedical Electronics Laboratory. In the following years, his research activities expanded to radio- and infrared biotelemetry, non-invasive measurements (blood pressure measurement), gait analysis and pulse plethysmography [21-23]. He published two textbooks: "Electronic instrumentation" and "Biomedical Electronics" [24]. For his research, Prof. Šantić was recognized internationally and at the national level. He was the first European BME researcher to receive the IEEE EMBS Career Achievement Award in 2003 for his "fundamental and pioneering contributions to the development and construction of EEG, EMG and ENG Instrumentation and for his leadership in creating biomedical engineering courses in Europe" [25, 26]. The EMBS Career Achievement Award is presented annually to an individual who has made significant contributions through a distinguished career of twenty years or more in the field of Biomedical Engineering, as an educator, researcher, developer or administrator. As a visionary, Prof. Šantić felt the growth of his most beloved field of engineering and promoted biomedical engineering in Croatia. He was the founding President of the Croatian Medical and Biological Engineering Society (CROMBES) [27], founded in 1992, continuing as the successor of the Croatian Section of the former Yugoslav BME Society (founded in 1984).

Today, CROMBES has over 100 members - scientists and experts involved in different scientific fields of biomedical engineering and medical physics. Since 1993, the Society has been a full member of the International Federation for Medical and Biological Engineering (IFMBE) and the European Federation for Medical Physics (EFOMP). Later the Society affiliated also to the International Organisation for Medical Physics (IOMP) and the European Alliance for Biomedical Engineering and Science (EAMBES).

6 BME RESEARCH IN CROATIA

Research activities in biomedical engineering in Croatia are carried out at the University of Zagreb, at the Faculty of Electrical Engineering and Computing, Faculty of Mechanical Engineering and Naval Architecture, School of Medicine, Faculty of Kinesiology and other institutions in Zagreb and other cities.

At the Faculty of Electrical Engineering and Computing, there are several research groups in this field. Research of the Electronic and Biomedical Instrumentation Group is devoted to biosignal measurement and processing methods [28], in particular of the heart [29], muscle [30-31] and the brain, as well as bioimpedance measurement methods [32] and instrumentation including characterization of bioelectrodes [33]. The research of computational modelling of electric [34] and thermal effects in tissue during electroporation-based treatments [35] is aimed to develop devices for minimally invasive therapeutic procedures in cancer treatment and for heart therapy. Networked sensor systems for physiological parameters monitoring and processing of extracted information in order to build up personalised intelligent mobile health systems for health care support represent a new field of research and development [36]. Research in the Sensors and Electronic Instrumentation Group includes a number of biomedical topics such as mathematical modeling for extraction of 3-D content from images [37] and methods, algorithms, and software packages that best implement these models, camera (self) calibration, 3D structured light scanning, image feature extraction, marker tracking, surface registration, computer vision theory and methods for human motion analysis.

Image Processing Group conducts research in theory and applications for intelligent image processing, pattern recognition and computer vision methods with applications in medical image analysis and biomedical imaging [38-39]. The main research problems include image feature extraction, image segmentation, image registration, and motion analysis. Research has been conducted for real-time intravascular catheter tracking from X-ray image sequences and 3-D reconstruction of catheter tip, and in cardiac applications, methods for atlas-based image analysis of aortic outflow velocity profile from ultrasound Doppler images have been developed. Methods for 3D CT image analysis of abdominal aortic aneurysm have been investigated, as well as segmentation methods for nuclear medicine image analysis, and methodology for quantitative analysis of intracerebral brain hemorrhage from CT images [40].

The Acoustics and Sonography Group develops sensors, devices and methods for medical application of ultrasound. They have developed an ultrasonic neurosurgical device and several methods for measuring acoustic power in low frequency ultrasound applications [41-42].

At the Faculty of Mechanical Engineering and Naval Architecture, a strong research group in biomechanics was founded under the leadership of Prof. Osman Muftić who designed the Croatian endoprosthesis of hip joint [43].

7 BME EDUCATION IN CROATIA

Education in the field of biomedical engineering started in Croatia in the early 1970s, as a part of biomedical electronics teaching at the University of Zagreb, Faculty of Electrical Engineering. Courses in biomedical engineering are offered by two Croatian universities: at the University of Zagreb, at several constituent units, and at the University of Split, BME courses are offered at the Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture. There is an action to establish a biomedical engineering programme at master level at the University of Zagreb supported by the international Tempus project "Curricula Reformation and Harmonization in the field of Biomedical Engineering" in which 23 European higher education or research institutions including University of Zagreb are participating [44].

8 CONCLUSION

Biomedical engineering is a young field of engineering and science and it is small compared to the traditional engineering fields, like electrical or mechanical engineering. However, due to the needs of the society and enthusiasms of young generations of BME students, the number of BM engineers working in research and development is rapidly growing. Most of the BM industry expands and labour market for BM engineers is expected to grow by 72% till 2018. Currently the fastest developing industries are active implants, medical imaging and mobile health services. New opportunities open in neural engineering, in interfacing the devices and the tissue, changing the cells and building artificial organs from artificial and biological materials, organisation of large datasets from biology, etc. BME research is so complex that hardly any research institution can cover all knowledge and skills necessary for successful outcome of the research goals alone. After 50 years of well institutionalized development of biomedical engineering at international level, and a little bit shorter development in Croatia, the Croatian engineers and scientists in the field contribute to the growing knowledge in the field of biomedical engineering.

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